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TEST ON A 2250 K. W. COMBINED HIGH PRESSURE RECIPROCATING STEAM ENGINE

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TEST ON A 2250 K.W. COMBINED HIGH PRESSURE RECIPROCATING STEAM ENGINE AND LOW PRESSURE TURBINE UNIT AT THE PLANT OF THE WISCONSIN TRACTION LIGHT HEAT & POWER COMPANY APPLETON WISCONSIN

by

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A Thesis submitted for the Degree of

BACHELOR OF SCIENCE

in the

Electrical Engineering Course

UNIVERSITY OF WISCONSIN

1911

INDEX

	Pages
Introduction	1 - 3
Equipment	4 - 8
Builder's Ratings and Guarantees	9 - 12
Test Equipment and Method	13 - 18
Object of Individual Tests	19 - 20
Results of Boiler Test	21 - 24
Summary of Results	25 - 27
Calculations	28 - 30
Conclusions	31 - 33
Comparisons	34 - 36
Original Data - Appendix	37 - 80

The exhaust steam turbine, one of the most modern of all forms of prime movers for electrical generating stations, has come into very general use within the last few years. Its wide adoption is due to its ability to efficiently utilize the exhaust steam from compound reciprocating engines, and it is being installed in a great many places where the latter form of prime mover is used. In addition to its high efficiency, the combined unit permits the use of high pressures and high superheats, since the range of steam volumes is greatly increased by the addition of the turbine in which the steam is fully expanded. As a result this means a low water rate per unit output, the energy available per pound of steam being greatly increased. Such an installation may be made without any material increase of floor space or pipe connections; while the output of the plant is greatly increased without scrapping any of the old machinery, or increasing the boiler room equipment.

The two exhaust steam turbines were installed at the plant in which the present test was made, to increase the output of a pair of nominally 1300 H.P.

tandem compound Corliss engines. The plant was formerly equipped with two generating sets, each consisting of a 500 K.W. direct current railway generator and a 500 K.V.A. 3 phase, 60 cycle, 4000/2300 alternator. These sets were driven on one end by a Victor water turbine, utilizing altogether about 2400 H.P. at this point on the Fox River. On the opposite end of each generating unit, the tandem compound engines were connected through clutches. In time of low water, and at peak loads, both engines and water wheels were connected to the generators. The engines were operated condensing, the cylinders being 19" and 40" x 36". To meet the change of conditions in operation with the exhaust turbines, the engines have recently been modified by changing the high pressure cylinders to 22 inches. It was, however, the intention of the engineers to use the original cylinders, but due to the blowing out of one of the cylinder heads it was deemed advisable to replace the old cylinders by new ones which would conform with the new operating conditions.

The low pressure turbines installed are 1250 K.W. 60 cycle Allis-Chalmers machines operating at 3600 R.P.M., with alternators delivering current at 4000/2300

volts.

The object of this test was to show what results can be obtained in a composite plant of this kind as compared with a plant in which only reciprocating engines or high pressure turbines are used.

EQUIPMENT

Boiler Room. The boiler equipment consists of two batteries, each battery containing two 345 H.P. Stirling water tube boilers. These are of an older hand fired type and are not equipped with coal or ash handling apparatus. Youghiogheny screenings were used as fuel. A car track entered the building and allowed the coal to be dumped immediately in front of the boilers. This track was of such a length as to allow three cars to be unloaded at once.

The water is pumped directly into the boilers from the hot-well by a pair of Prescott 12" x 6" x 12" Potform plunger pumps. No feed-water heater is used. The total area of water heating surface per boiler is 3450 square feet. The steam is superheated by a Foster superheater, whose area is 600 square feet per boiler. This gives a superheat of about 140 degrees Fahrenheit at 150 pounds pressure. During the test only one feed pump was used, and the amount of water was controlled by a separate valve at each boiler. The steam was led from each boiler to a ten inch header in the engine room by six inch pipes. All pipes are covered with magnesia pipe covering.

Engine Room. The steam is taken from the header to the engine throttle by horizontal and vertical six inch piping. Just before entering the throttle the pipe is provided with a pop valve which is set to blow at a pressure of twenty pounds above normal. All engine room equipment is in exact duplicate in all details, and for this reason but one of the two installations will be described. The engines are tandem compound 22" and 40" x 36" with horizontal cylinders lagged with 2-1/2" covering of 85 per cent magnesia. The high pressure cylinder has a standard Corliss releasing gear, while the low pressure has no cut-off. The engine receiver is supported horizontally above the two cylinders by the steam connections to the cylinders, which arrangement gives the minimum amount of pipe connections. The steam exhausted from the low pressure cylinder of the engine passes through a Cochrane horizontal oil and water separator, which removes all cylinder oil and condensation. The water and oil is drained from the separator through a pair of Crane tilt traps. The separator acts as a small receiver from which the steam passes to the turbine. From the latter it is exhausted into a Prescott surface condenser containing

4500 square feet of cooling surface. No pump is necessary to furnish the condenser with cooling water, as the head of the river provides a sufficient flow by gravity from the flume at all times. The vacuum is maintained by a 10" x 18" x 16" Prescott positive dry vacuum pump which exhausts into the turbine receiver. The condensed steam was pumped from the condenser by a 5 H.P. induction motor, driving a 2-1/2" volute centrifugal Prescott pump, into weighing tanks, from which it passed to the hot well.

GENERATORS.

The generating equipment, with the exception of the turbo-generator, has already been described in the introductory paragraph. The latter was an Allis-Chalmers 1250 k.v.a. 4000/2300 volt, three phase, 60 cycle alternator, 3600 R.P.M. Excitation for the three generators was furnished by a water turbo-driven 125 volt 32.5 k.w. machine.

The steam turbine is of the Parson's type, as manufactured by the Allis-Chalmers Company. It is connected to the engine by a twenty-one inch pipe, and to the condenser by a twenty-eight inch exhaust pipe. An emergency connection was also made with the turbine permitting live steam to be supplied in case of an accident to the engine. Oil is supplied to all bearings by a pump direct connected to the turbine shaft. The oil is returned to the pump after passing through a water cooler and is then recirculated. When starting up, the oil is supplied to the oil relay governor by a small steam driven pump. The speed of the turbine is regulated by a governor driven from the turbine shaft by means of cut gears working in an oil bath. The governor operates a balanced throttle valve by means of

a relay. Adjustment of speed may be made while the turbine is in operation and thereby facilitates the synchronizing of the alternators.

Switchboard. The switchboard consists of several slate panels located on the main floor immediately behind the engine. On it are mounted the integrating and indicating wattmeters, voltmeters, ammeters, Tirrell voltage regulator, and the field rheostats. The step-up transformers for interurban transmission are located in the gallery.

A 40,000 pound electrically operated Pawling & Harnischfeger traveling crane completes the engine room equipment.

BUILDER'S RATINGS AND GUARANTEES.

Boilers

Kind - Stirling water tubular boilers

Number of boilers installed	4
Number of boilers used during test	3
Number of batteries	2
Number of boilers in each battery	2
Rated boiler H.P. (each)	345
Square feet of heating surface (each)	3450
Square feet of grate surface (each)	70.69
Steam drum	36" x 14" x 9"
Mud drum	42" x 13" x 3"
Thickness of steam drum	9/16"
Thickness of mud drum	5/8"

Condenser Circulating Pump

Make - Prescott Steam Pump Company
Size Duplex 10" x 14" x 18"
Capacity - 2000 gal. per minute against 35' head

Boiler Pump

Make - Prescott Steam Pump Company
Size Duplex 12 x 6 x 12"
Capacity - 150 to 200 gal. per minute against pressure of 150 lbs.

Engines - Corliss Type

Make - Allis Chalmers, reciprocating type
Size - 22" & 40" x 36"
Tandem compound engine
Speed - 150 R.P.M.
Diameter of piston rods - 3-3/8" & 4-3/8"
Steam travel not to exceed 100 ft. per second
Weight of fly wheel - 30000 lbs.
Main journal 16" x 28"
Diameter of fly wheel - 12'
Face of fly wheel - 17"

Turbine

Kind - Allis Chalmers, low pressure
Maximum rating - 1250 K.W.
Speed of turbine - 3600 R.P.M.

Turbo Generator

3 Phase, 60 Cycle, 4000 Volts
Guarantees:
- 29" vacuum
- 30" barometer
- Consumption of dry steam not to exceed the following:
  - Capacity of 500 K.W. with 33.1# of steam per K.W. per hour
  - " " 750 " with 29.5# of steam per K.W. per hour
  - " " 1000 " with 27.5# of steam per K.W. per hour
  - " " 1250 " with 26.9# of steam per K.W. per hour

Operation of turbo under 100% power factor
180 Amperes per terminal
Steam pressure at turbine throttle 17# absolute
Temperature of steam at turbine throttle 290° F.
Vacuum at 28 and 29" mercury
100% power factor for 24 hours
Rise of 50° C. for rotor excitation for 120 volts

80 Amperes at full load and 100% power factor
Intake on low pressure on turbine = 14"
Intake on high pressure of engine = 8"
Intake on turbo for live steam = 3-1/2"
Intake on low pressure of engine = 14"
High pressure exhaust = 9"
Outlet from turbine to condenser = 28"
Weight of turbine 60000 lbs.

Condenser

Number of condensers	2
Make - Prescott Steam Pump Company	
Sq.ft. of condensing surface (each)	4500
Number of tubes in each condenser	1720
Outside diameter of tube	1"
Inside diameter of tube	.902"
Connection of tubes (B.W.gauge number)	18
Length of tubes	10'
Form of shell -	cylindrical
Width of shell	6'
Height of shell	7'
Length of shell	13'6"
Conditions of service:	
Capacity in pounds of exhaust steam per hour	34000
Temperature of condensing water	60° F.
Temperature of discharge water	71° F.
Amount of condensing water per minute, gals.	5500
Vacuum in inches of mercury based on 30" barometer	

Vacuum Pump

Make - Prescott Vertical Positive Rotative Dry Vacuum Pump

Dimensions:

Diameter of steam cylinder	10"
Diameter of air cylinder	18"
Length of stroke	16"

Conditions of service:

Steam pressure pounds per square inch	150
Displacement in cubic feet per revolution	4.714
Revolutions per minute	100
Displacement in cubic feet per minute	471

Pipe size:

Diameter of steam pipe	2.5"
Diameter of exhaust pipe	3.5"
Diameter of air inlet	6"
Diameter of discharge pipe	5"
Diameter of jacket water circulating inlet	1-1/4"
Diameter of jacket water circulating outlet	1-1/4"

Floor space:

Length	5' 4"
Width	5'
Height	13' 8"

Detail:

Diameter of shaft in main bearing	4"
Length of shaft in main bearing	8"
Diameter of crank pin	3"
Length of crank pin	3"
Diameter of cross-head pin	2-1/4"
Length of cross-head pin	3"
Diameter of fly wheel	4' 9"
Weight of fly wheel	1300 lbs.

Circulating Pump

1 - 2-3/4" Centrifugal pump direct connected to a 5 H.P. 1200 R.P.M., Form "K", 220 volt, 3 phase, 60 cycle induction motor

Superheater

Kind - Foster
Builder - Power Specialty Company

Number of superheaters	4
Number of superheaters in each boiler	1
Square feet of superheating surface (each)	600

Guarantee: Superheaters are guaranteed to raise the temperature of 10,500 lbs. of steam per hour at a pressure of 150 lbs. per sq. in. to 465° F. corresponding to superheat of 100° F.

TEST EQUIPMENT AND METHOD.

The test was conducted as nearly as possible according to the method prescribed by the American Society of Mechanical Engineers.

The coal was weighed in wheel-barrows and then dumped on the floor immediately in front of the boilers. The barrows were then weighed back. At the end of each hour the total weight per hour was calculated by taking the total coal weighed and subtracting the estimated amount on the floor. At the conclusion of each run all coal remaining on the floor was weighed back and the amount subtracted from the total amount weighed.

As the runs were relatively short, no effort was made to determine the amount of ash, as this would not give the true boiler performance under average operating conditions.

The water was weighed in two steel tanks, which in turn emptied into a large receiving tank. Separate valves control both the inlets and outlets of these tanks. The water weighed was the condensed steam from the condenser, and was pumped directly into the boilers from the receiving tank. Make up water was

added to the weighing tanks whenever necessary. The two weighing tanks were placed on platform scales and were weighed each time, both before and after being dumped.

The flue gas analysis consisted of a determination of the CO_2 by means of an Orsat apparatus. The apparatus was connected to the stack by means of a long tube which entered the flue just above the boilers. Before any sample was taken the old gas remaining in the tube from the previous sample was pumped out by means of a small rubber suction bulb. The sample was then taken from the flue by means of two siphoning bottles. Samples were taken and the CO_2 determined at convenient intervals approximating every half hour.

The draft in the stack was determined by means of a U-shaped water gage. The temperatures of the flue gases were taken at the stack entrance with a special thermometer, which was provided with an oil cup and reflector. By placing an electric light in front of the reflector it was possible to read the scale from the boiler room floor. A thermometer similar to this was placed in the steam line just ahead of the engine throttle. A Crosby gage was also connected at this

point for determining the line pressure. The engine receiver was likewise provided with a pressure gage, but due to the varying of pressure, readings could not be taken with any degree of accuracy. Engine speeds were computed from the readings of a continuous counter and also directly from a tachometer. Readings on all these instruments were taken every fifteen minutes during all tests. Indicator cards were taken on outside spring Crosby indicators. Double cards were taken on the high pressure end every ten minutes, and every five minutes on the crank and head ends respectively of the low pressure side. On account of the piping system only one indicator could be attached to each cylinder. The reducing motion for the indicators consisted of a wooden pantograph which was securely fastened to the floor and to the cross head of the engine. The temperature of the steam was taken again at the entrance to the turbine, and also in the Thomas electric calorimeter which was placed at this point. Temperatures of the cooling water at the entrance and discharge of the condenser were taken, as well as that of the condensed steam. The Thomas calorimeter was selected for determining the quality of the steam entering the turbine,

as it works very satisfactorily on almost any quality of steam. It consists of several comparatively high resistance coils enclosed in a heavy bronze shell. A sampling pipe was placed in the line and connected to the calorimeter. The wet steam entering the calorimeter was superheated by an electric current flowing in the resistance coil. The power thus expended was read on a wattmeter in the line, and the amount of power to superheat was controlled by a water rheostat. Superheat may be determined in two ways, either by observing the sudden rise in temperature in the calorimeter, or by watching for the condensation to disappear from a glass tube in the steam line. The steam, after passing through the calorimeter, was condensed by causing cold water to circulate about the steam pipe. This condensation was caught in a receiver and carefully weighed. By knowing the time it took to condense this steam, its weight and the power used to superheat it, the quality was easily determined.

It was quite necessary in the test to have the same vacuum on the calorimeter condenser as on the main steam line. It was also necessary to lag the calorimeter and sample pipe with pipe covering.

The electric load consisted of one D.C. water rheostat and one A.C. The D.C. rheostat was made up of sixteen 48" x 36" x 1/8" sheet iron plates spaced four inches apart in a wooden frame. The plates were alternately connected to the positive and negative leads of the generator. The frame was then suspended in the swift current of the river by means of a block and tackle. Any desired load could thus be obtained by varying the area submerged. The A.C. rheostat consisted of three right angle triangular plates whose legs measured 36" x 48". These were attached by the shorter leg to a wooden frame, which was an equilateral triangle in shape measuring ten feet on each side. The plates were hung on the medians of the triangle, the distance from center to center being about four feet. This frame was also suspended in the river in the same manner as the D.C. rheostat, the load as before being controlled by the area submerged.

All electrical readings were taken from standard instruments which were installed on the switchboard for this special test. Each generator, as well as the exciter, was provided with separate instruments. The D.C. instruments were connected directly in the

line, while with the A.C. the current carrying instruments, consisting of ammeters, indicating and integrating wattmeters, were connected through a current transformer. The voltages were measured through a potential transformer connected between the line and the ground. All A.C. readings were taken every fifteen minutes on each phase. D.C. readings were taken at the same time.

OBJECT OF INDIVIDUAL TESTS.

Test No. 1 was run with about three-quarters load on the engine or one-half load on the complete unit. In this test the water was pumped into the boilers directly from the hot-well, its weight being determined as in the other test, but no determination was made of the steam condensed in the turbine condenser. The fourth test was run for the purpose of determining the difference between the weight of the water supplied to the boilers per hour, and the condenser discharge per hour. This determination was made in accordance with the method outlined under "Calculations". Tests No. 2 and No. 3 were run with practically the same load. It was necessary to discontinue test No. 2 due to the flooding of one of the boilers. Test No. 3 was then run with the same load. The condenser water was weighed in this test and make up water was added to the hot-well as needed. It was the original intention to run at least two more tests on the plant at fractional loads, but due to unforeseen accidents and difficulties and the uneconomical use made of the power, it

was necessary to discontinue the tests with three-fourths and full load on the engine, which give a corresponding load on the turbine of one-half and three-fourths load.

A one-half hour test was made on the condenser to determine whether or not water was leaking through the tubes. The results showed that all parts were tight and that no leakage was taking place.

RESULTS OF BOILER TEST

Date - January 25 & 26, 1911

Kind of boiler	Stirling
Manufactured by	Babcock & Wilcox Company

		Test No.1	Test No.2	Test No.3
Duration of test	hrs.	4	2	4
Kind of furnace			Hand fired	
Grate surface	sq.ft.	70.8	70.8	70.8
Water heating surface	"	3450	3450	3450
Superheating surface	"	600	600	600
Ratio of heating to grate surface		48.7	48.7	48.7

Pressures

		Test No.1	Test No.2	Test No.3
Barometer	in.mercury	29.32	29.02	29.02
Steam gage	lbs.	150	150.4	148.7
Absolute	"	164.4	164.7	162.9
Draught, gage	in.water	.74	.65	.61

Temperatures

		Test No.1	Test No.2	Test No.3
External air	deg. F	41	41	41
Boiler room	"	60	60	60
Escaping gases	"	514	558.1	533.1
Feed water	"	47.35	51	54.8
Steam	"	491.5	483.5	501

Fuel

Kind of coal	Youghiogheny
Locality	Pittsburg
Size of coal	Screenings

		Test No.1	Test No.2	Test No.3
Fix carbon	%	83.6	83.6	83.6
Volatile matter	%			
Moisture	%	5.2	5.2	5.2
Ash	%	11.2	11.2	11.2
B.t.u.per lb.of dry coal		13131	13131	13131
B.t.u.per lb.of combustible		14885	14885	14885
Total coal consumed	lbs.	14025	8535	18910
Dry coal consumed	"	13296	8100	17964
Total combustible	"	11740	7140	15815

Combustion per Hour

Dry coal	lbs.	3324	4050	4491
Combustible	"	2935	3570	3954
Dry coal per sq.ft of grate surface	"	15.7	19.1	21.1
Combustible per sq.ft.of grate surface	"	13.8	16.8	18.5
Dry coal per sq.ft. of heating surface	"	0.321	0.392	0.483
Combustible per sq.ft.of heating surface	"	0.283	0.345	0.382
CO_2 - Per cent of volume-	Orsat	5.86	7.8	7.2
Quality of steam			Superheat	
Superheat	degrees F	128	120	138

		Test No.1	Test No.2	Test No.3
Water				
Total weight of water used	lbs.	87189	54495	108821
Total evaporated - dry steam	"	87189	54495	108821
Factor of evaporation		1.289	1.28	1.283
Equivalent evaporation from and at 212° F.	lbs.	112300	69650	139850
Water per Hour				
Amount used	lbs.	21797	27247	27205
Evaporated - dry steam	"	21797	27247	27205
Equivalent evaporation from and at 212° F.	"	28075	34825	34963
Economic Evaporation per Pound of Fuel				
Actual, per lb. of dry coal	lbs.	6.56	6.72	6.05
Equivalent from and at 212° F. (dry coal)	"	8	8.16	7.37
Actual, per lb. of combustible	"	7.44	7.6	6.85
Equivalent from and at 212° F. (combustible)	"	9.05	9.25	8.35
Rate of Evaporation				
Per sq.ft. of Grate Surface per Hour				
Actual, from feed water temperature	lbs.	103	128	128
Equivalent from and at 212° F.	"	132	164	165

		Test No.1	Test No.2	Test No.3
Rate of Evaporation				
Per Sq.ft. of Water Heating Surface per Hour				
Actual,	lbs.	2.1	2.63	2.63
Equivalent from and at 212° F.	"	2.71	3.37	3.37
Coal cost to evaporate 1000 lbs. of water from and at 212. F.	cents	20.63	20.2	22.3
Horse Power				
On basis of 34.5 pounds equivalent evaporation per hour	H.P.	271	338	338
Builder's rating	"	345	345	345
Ratio of H.P. developed to builder's rating		0.786	0.98	0.98
Heat Balance				
Heat absorbed per lb. of dry coal	B.t.u.	7490	7920	7150
Heat absorbed per lb. of combustible	"	9800	10175	9240
Heat lost per lb. of coal	"	5395	5215	6000
Efficiency of boiler	%	55.8	68.4	62
Efficiency of boiler and grate	%	59	60.3	54.4

SUMMARY OF RESULTS.

Steam Engine

	High Pressure		Low Pressure
Kind of engine		Corliss	
No. of cylinders	1		1
Dia. of cylinders	22"		40"
Dia. of piston rod	3-3/8"		4-3/8"
Stroke of piston	3'		3'
Ratio of cylinders	1	to	3.32
Area of piston - head end (sq.in.)	380.13		1247
- crank " "	371.2		1241

		Test No.1	Test No.2	Test No.3
Character of steam		Superheat		
Duration of test	hrs.	4	2	4
Weight of feed water consumed	lbs.	87189	54495	108821
Feed water consumed per hour	"	21820	27247	27205
Steam entering engine per hour	"	20498	25685	25653
Pressure of steam at throttle (absolute)	"	160.4	162.28	161.18
Temperature of steam at throttle	Deg.F.	491.5	483.5	501
Degrees superheat	"	128	120	138
Barometric pressure	in.mercury	29.32	29.02	29.02
Receiver pressure - gage	lbs.	4.29	10.1	10.6
Back pressure on engine - (absolute)	"	11.65	16.42	16.55
Revolutions per minute		147.5	146.4	146.4
Kilowatt hours- total on engine		2873	1794	3568
Kilowatts per hour on engine		718.3	897	892
M.E.P.- head end - H.P. cylinder		90.2	96.7	94.4

		Test No.1	Test No.2	Test No.3
M.E.P. - crank end - H.P.cylinder		84.4	98.8	95.3
M.E.P. - head end - L.P. cylinder		5.63	8.21	7.86
M.E.P. - crank end - L.P. cylinder		5.35	7.84	7.46
I.H.P. - H.P. cylinder		880	978	950
I.H.P. - L.P. cylinder		183	266	254
Total I.H.P. - engine		1063	1244	1204
Feed water consumed by engine and auxiliaries per K.W. hour	lbs.	30.4	30.4	30.5
Feed water consumed by engine per K.W. hour output	"	28.6	28.6	28.7
Feed water consumed per electrical H.P. hour	"	21.4	21.4	21.5
Feed water consumed per I.H.P. hour	"	19.35	20.6	21.5
Efficiency ratio		55.8	58.2	60

Turbine

		Test No.1	Test No.2	Test No.3
Capacity full load	K.W.	1250 ~~12,50~~	1250 ~~12,50~~	1250 ~~12,50~~
Duration of test	hrs.	4	2	4
Pressure steam entering turbine (absolute)	lbs.	10	12.9	13
Quality of steam entering turbine	%	97.2	96.3	96.8
Condensed steam from turbine	lbs.	78150	49223	97276
Total dry steam entering turbine	"	76000	47430	94150
Temperature of steam entering turbine	Deg.F.	192.2	206.5	207.4
Barometric pressure	in.mercury	29.32	29.02	29.02
Vacuum observed	"	28.05	27.76	27.82
Vacuum referred to 30" barometer		28.73	28.74	28.8

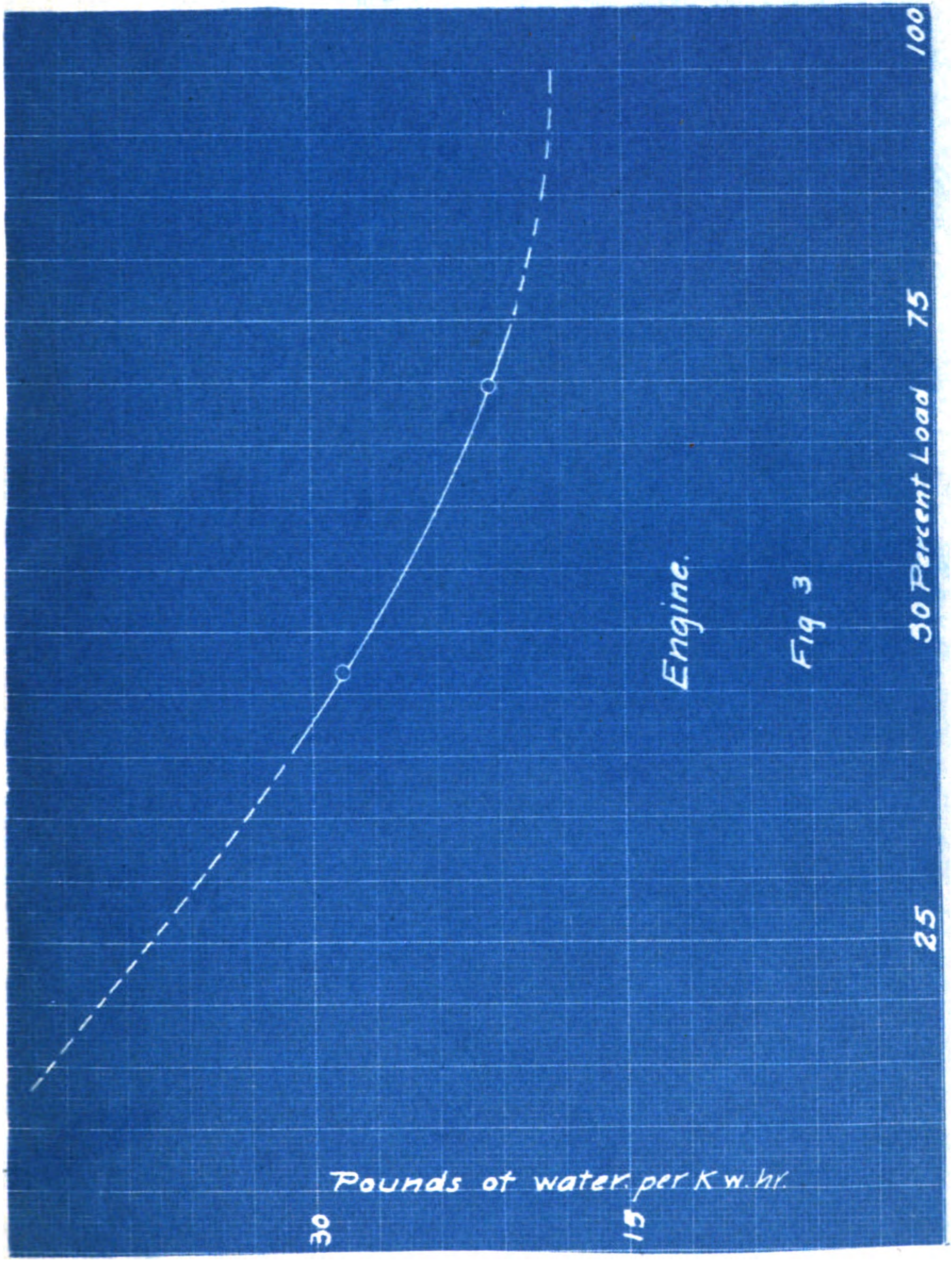
	Test No.1	Test No.2	Test No.3
K.W.hours - total turbine	1910	1371	2882
K.W.output per hour - turbine	477.5	685.5	720.5
Steam per K.W. per hour (dry)	40	34.5	32.6
Steam per electrical H.P.hour (dry)	29.85	25.75	24.3
Efficiency ratio	56	61	60.3

Complete Plant

Total K.W. hours output		4783	3165	6450
K.W. per hour		1193	1582	1613
Total steam used	lbs.	87189	54495	108821
Total steam entering turbine	"	78150	48723	97276
Steam removed	"	9039	5772	11545
Steam per K.W. hour	"	18.3	17.2	16.9
Steam per E.H.P. hour	"	13.68	12.85	12.61
Dry coal per K.W. hour	"	2.79	2.55	2.8
Dry coal per E.H.P. hour	"	2.08	1.905	2.09
Thermal efficiency - coal to switchboard	%	9.4	10.3	9.3

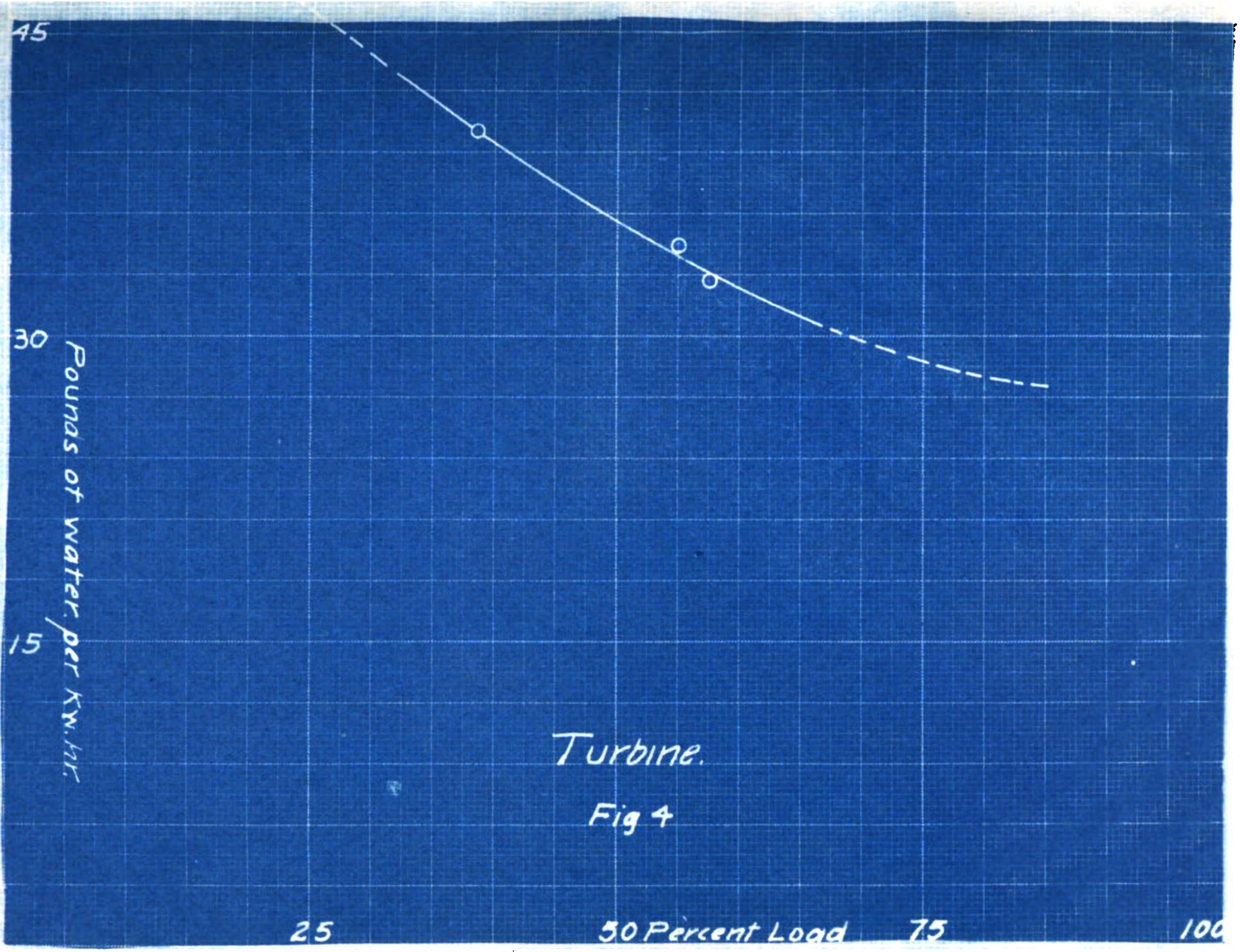
Combined Unit

Total K.W. hours output		4783	3165	6450
K.W. per hour		1193	1582	1613
Total steam used by combined unit per hour	lbs.	20623	25823	25793
Steam used per K.W. hour	"	17.28	16.2	16
Steam used per E.H.P.hour	"	12.9	12.2	11.98
Thermal efficiency - combined unit	%	15.7	16.8	16.82
Efficiency ratio	%	53.8	54.3	53.7



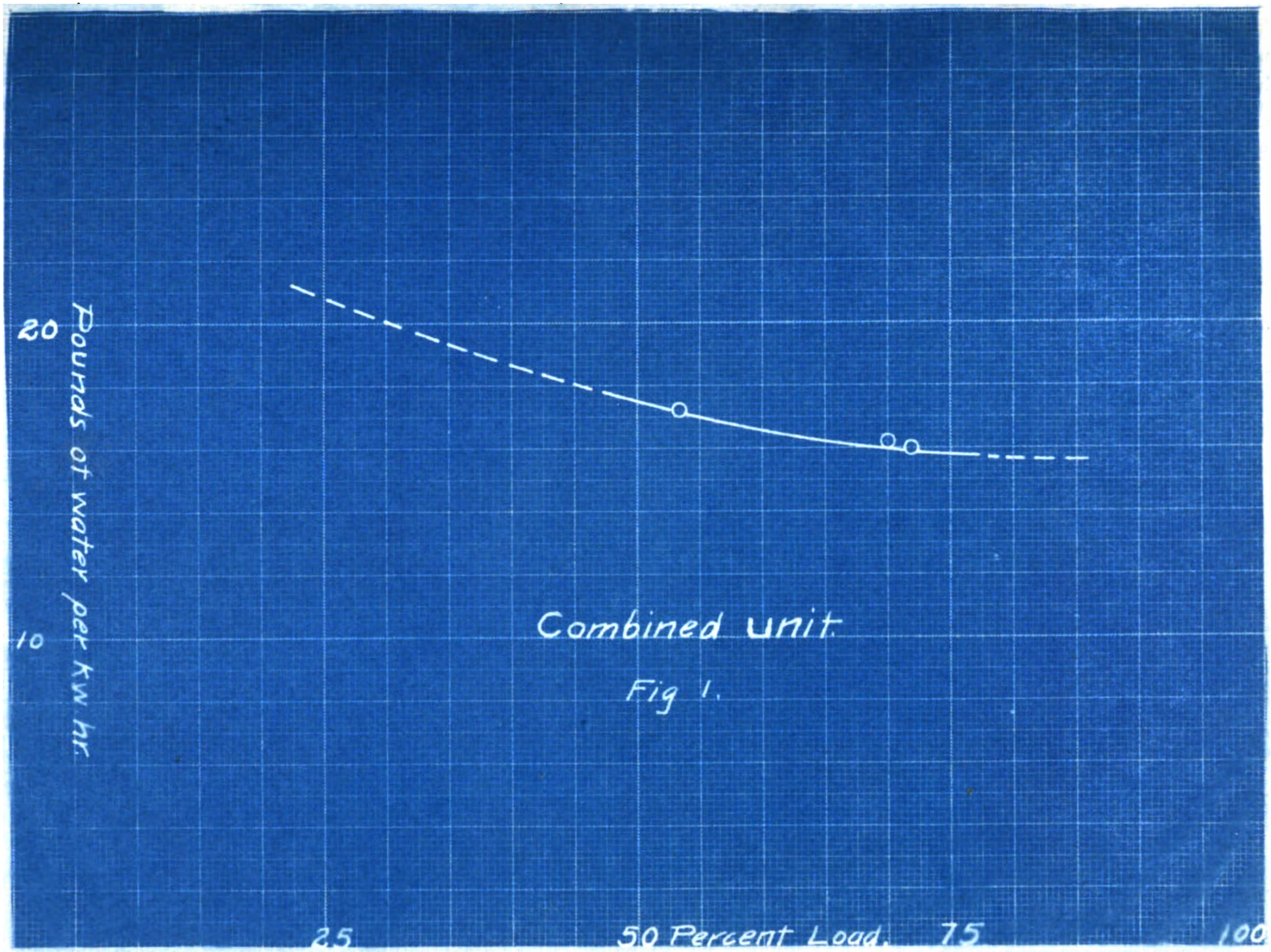
Engine.

Fig 3



Turbine.

Fig 4



Combined Unit.

Fig 1.

CALCULATIONS

The actual amount of steam entering the engine was determined in the following manner: the total amount of water evaporated per hour was determined from the amount of the feed water. This furnished steam for the engine and also supplied the feed water pump and the dry vacuum pump. It was therefore necessary to determine approximately the steam used by these auxiliaries. Considering test No. 1, the feed water pump lifted 21,820 pounds of water per hour against a steam pressure of 150 pounds. Each pound of water is equivalent to a head of 2.3 feet. Hence the horse power developed equals

$$\frac{21820 \text{ x } 150 \text{ x } 2.3}{33000 \text{ x } 60} = 3.8 \text{ H.P.}$$

Assuming that the pump, which is an old one, used 250 pounds of steam per horse power, the steam consumption per hour would be equal to 3.8 x 250 lbs. = 950 lbs.

From an investigation of the performance of vacuum pumps similar to the one in this installation it was estimated that the pump was developing 6.2 horse

power using 60 pounds of steam per hour per horse power, or a total of 372 pounds per hour. This gives a total of 1322 pounds of steam used per hour by the auxiliaries. Deducting this from the total water pumped by the feed pump leaves (21820 - 1322) = 20,498 pounds used by the engine. The evaporation from the tanks and the condensation drained by the traps is equal to the difference between the amount used by the engine (20,498 pounds) and the weight of the condensed steam pumped from the turbine per hour (19,536 pounds), or a difference of 962 pounds.

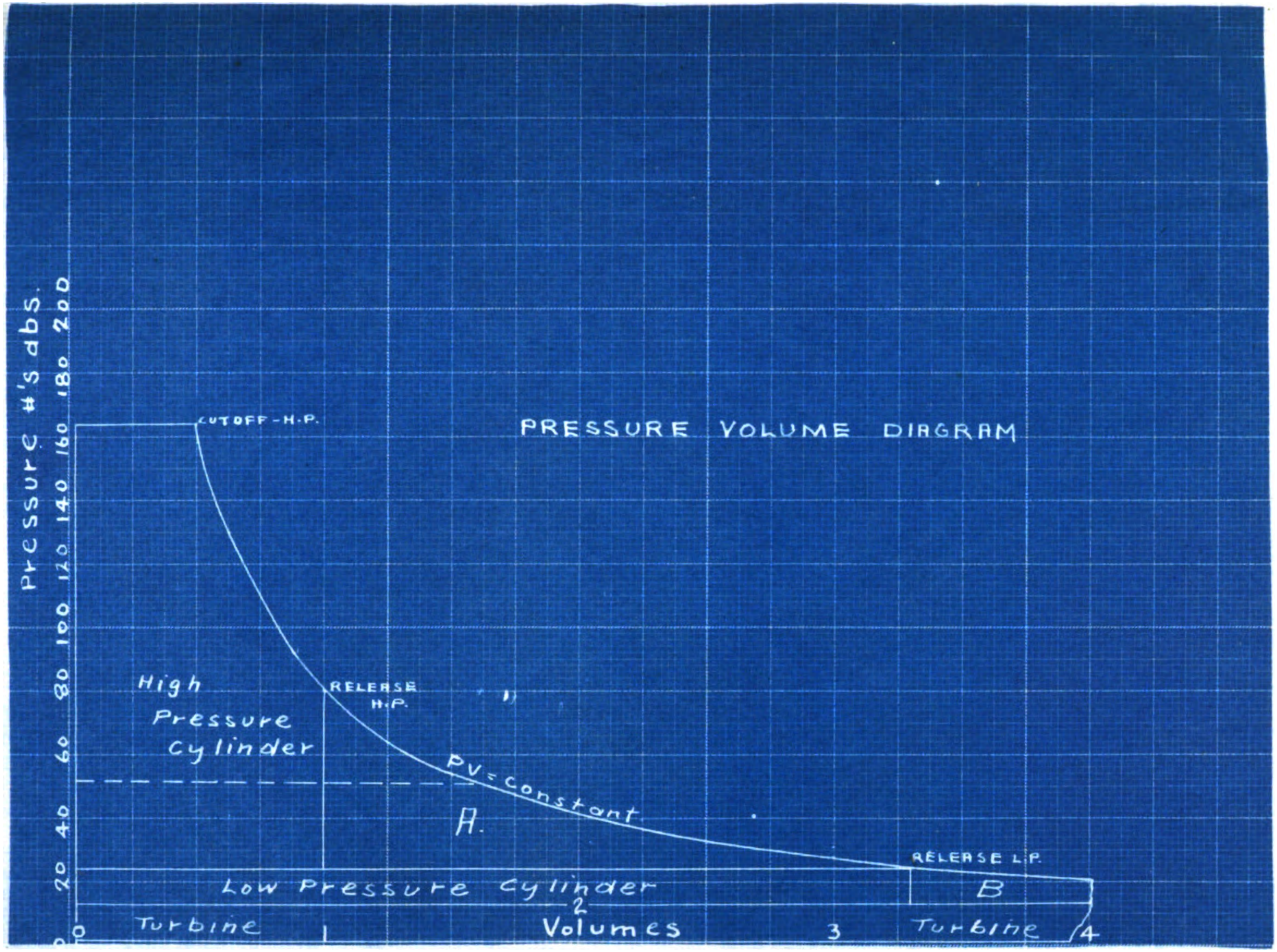
The total steam used by the combined unit was calculated as follows: Considering test No. 2, the total steam entering the engine is 25,685 pounds. This exhausts into the turbine together with the exhaust from the vacuum pump, which is 372 pounds per hour. Assuming that the latter is 95% dry, the total dry steam from the vacuum pump is .95 x 372 pounds = 340 pounds. The engine used 26.65 pounds of steam per kilowatt hour, the turbine 34.7 pounds. In the former case the kilowatts per pound of steam equals .035, and in the latter case .029, or a total of .064 kilowatts

per pound of steam. Hence the amount of steam to be added per hour to the combined unit is 29/64 of 304 pounds, or 138 pounds, giving a total consumption by the combined unit of 25,685 pounds plus 138 pounds equals 25,823 pounds. This value was used to calculate the steam consumption per kilowatt and per electrical horse power hour.

CONCLUSIONS

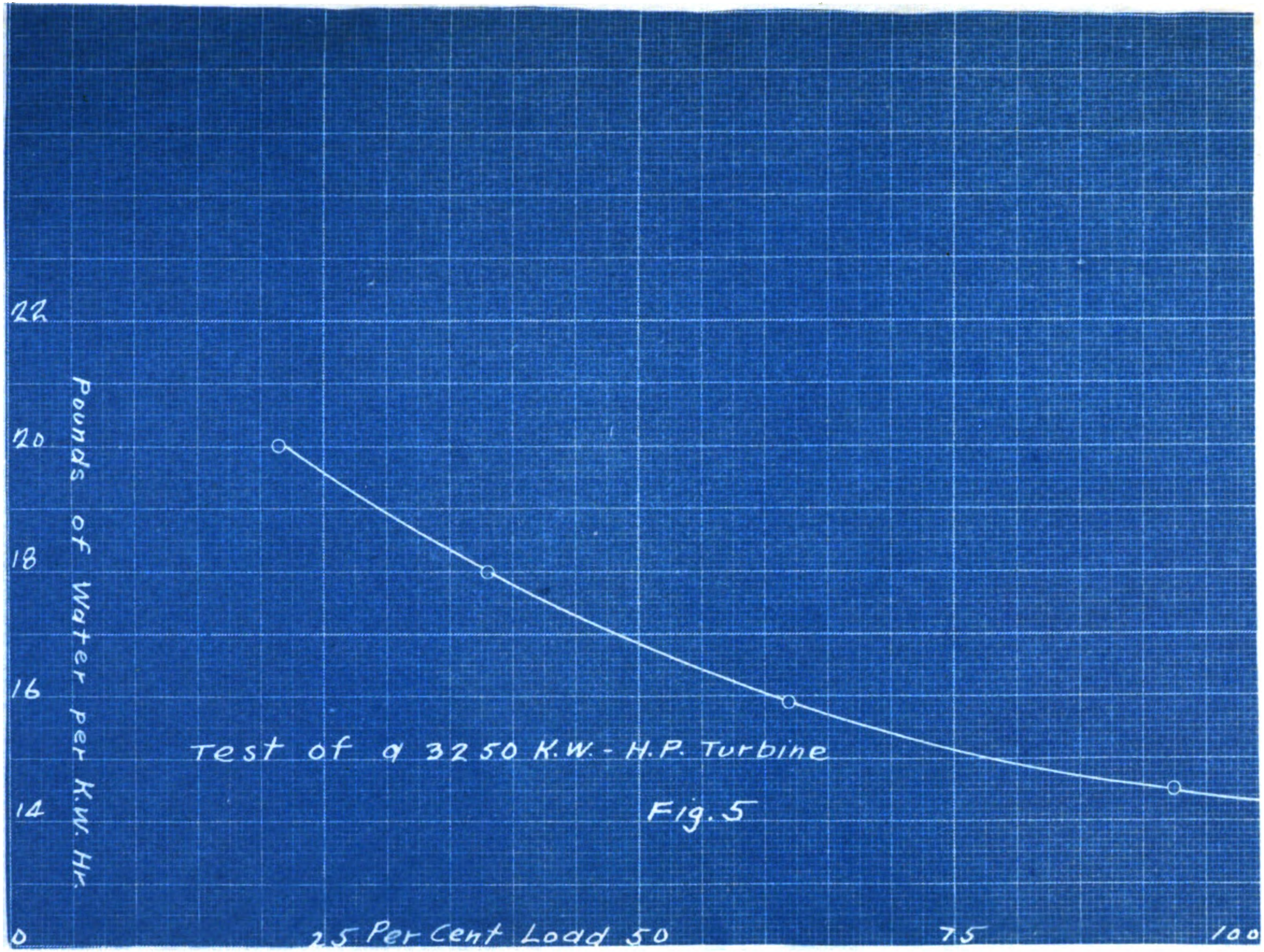
The high pressure cards show that the high pressure cylinder is developing its maximum horse power. An examination of the data and the low pressure cards will show that the low pressure cylinder is doing but one quarter of the work of the high pressure cylinder. This results in an unbalancing of the engine which causes considerable pounding. It will be noted that there is a negative loop on the low pressure cards. This is due to too small a clearance volume for the working pressure and too early compression.

A pressure-volume diagram has been drawn using pressures as ordinates and volumes as abscissas. Assuming about four per cent clearance and fifty per cent cut-off on the high pressure cylinder, which corresponds to that obtained in the tests, the curve PV, equals a constant, was drawn. The area under this curve was divided according to the pressures and volumes of the high and low pressure cylinders respectively. Expansion in the high pressure cylinder occurs from cut-off to release, and then drops to the receiver pressure. The low pressure cylinder takes in steam the full


PRESSURE VOLUME DIAGRAM
Pressure #'s abs.
0
20
40
60
80
100
120
140
160
180
200
CUTOFF - H.P.
RELEASE H.P.
High Pressure cylinder
PV = constant
A.
RELEASE L.P.
B
Low Pressure cylinder
Turbine
Turbine
Volumes
0
1
2
3
4

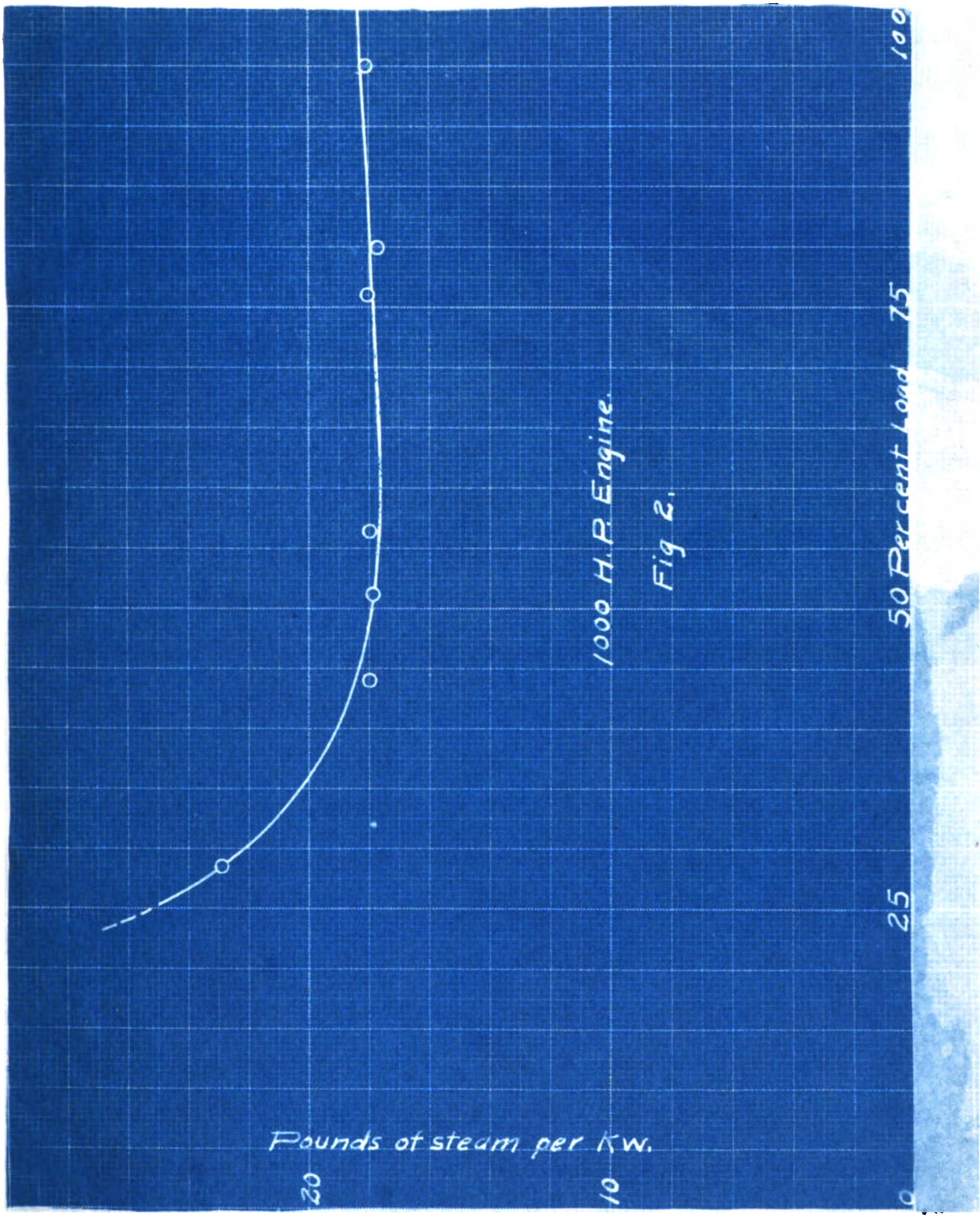
length of the stroke and then drops down to the turbo receiver pressure. The diagram shows that there is a large area "A" which is lost, due to the low receiver pressure between the two cylinders. In order to make the unit work efficiently and utilize part of this area "A" it would be advisable to put a release gearing on the low pressure cylinder. This would increase the back pressure on the high pressure cylinder and cut down the amount of work done by the high pressure cylinder and increase the work done by the low pressure cylinder. This would equalize the loads on the two cylinders. In addition to this it would allow expansion to take place in the low pressure cylinder and make use of part of the lost area "A". Such an improved condition is shown by the dotted line on the diagram. By comparing the lost areas in the two cases it is seen that it is possible to reduce the lost area to approximately one-sixth its former value. This would also result in a smaller steam consumption due to a greater power output per pound of steam with this release gear. A rough estimate of this steam consumption would be about 14.5 pounds per kilowatt hour at the load carried.

The turbine installed in the plant is a 1250 kilowatt, but at the maximum allowable load on the engine the turbine was operating at but little better than one-half load. If a smaller turbine had been installed the efficiency of the plant would have been higher. A possible excuse for such a large turbine unit may be as follows: The engines are old and it is probably the intention of the company to install new and larger engines in the near future. This will also necessitate a new boiler equipment.



Test of a 3250 K.W. - H.P. Turbine

Fig. 5



1000 H.P. Engine.

Fig 2.

COMPARISONS

It is rather a difficult matter to obtain data on other units of approximately the same capacity as the unit tested. The water consumption of a 3250 kilowatt high pressure Allis-Chalmers turbine unit is plotted on curve sheet No. 5. The data for this curve may be found in a paper entitled, "Test of a 3250 K.W. Steam Turbine", by Professor R. C. Carpenter in the Sibley Journal of Engineering, January 1911. A comparison between this and the combined unit tested is possible. While the high pressure machine takes 17 pounds of steam at half load and 14.3 pounds at full load, the combined unit under test takes 17.6 pounds at half load and 16 pounds at full load. For equal outputs of 1700 kilowatts the water consumption for the high pressure turbine is 16.8 pounds per kilowatt hour and for the combined unit it is 16 pounds per kilowatt hour. This would not indicate any particular advantage in favor of the combined unit. The water rate for the combined unit will no doubt be considerably reduced when the release gearing is placed on the low pressure cylinder of the steam engine.

In considering the above comparisons it should be kept in mind that the high pressure turbine is of considerably larger size and, hence, on that account should be more economical. The high pressure turbine results are the best that have been obtained up to date on any American steam turbine, and hence the above comparison of units hardly represents average operating conditions.

Previous to the installation of the low pressure turbine the engine under test was taking 21 pounds of steam per kilowatt hour at full load when operating condensing. Results indicate a considerable saving by the new installation.

Comparing the combined unit tested with a test on a 1000 horse power engine in the American Sugar Refining Company's plant at Brooklyn, New York, which was made by Professor D. S. Jacobus of theStevens Institute of Technology, we find that at half load the above engine took 18 pounds of water per kilowatt hour, while the combined unit under test took 17.6 pounds. At three-quarters load the engine took 17.8 pounds of water per kilowatt hour while the combined unit at this load takes but 15.8 pounds. The curve of the engine

has reached its minimum water rate at this load, while that of the combined unit is still inclined downward. The water rate of the combined unit would probably be about 15 pounds at full load. With a release gear on the low pressure cylinder the water rate would probably be reduced to 14 pounds per kilowatt hour at full load. This would compare very favorably with the best of installations.

LOG OF BOILER TEST NO.1.

Kind of boiler	Stirling
Location of boiler	W.T.L.H.& P.Co.,Appleton,Wis.
Number of boilers	Three
Size of each boiler	345 H.P.
Total water heating surface	3450 sq.ft. each
Superheating surface	600 " "
Weather	Drizzling rain
Barometer	29.32 inches
Date of test	January 25, 1911 .

	Pressure		Temperature F°			
Time P.M.	Steam gage	Stack draft in. water	Stack temp.	Feed water	Steam at engine	Water level in gage glass
12:00	148.0	0.65	500.0	53.0	467.0	One inch above mark
12:15	150.0	0.70	505.0	50.0	470.0	
12:30	149.0	0.65	480.0	50.0	485.0	
12:45	147.0	0.80	530.0	51.0	484.0	
1:00	150.0	0.75	535.0	51.0	494.0	
1:15	148.0	0.50	480.0	51.0	495.0	
1:30	148.0	0.70	530.0	48.0	485.0	
1:45	149.0	0.90	525.0	46.0	498.0	
2:00	150.0	0.70	525.0	46.0	500.0	
2:15	150.0	0.70	525.0	46.0	504.0	
2:30	150.0	0.80	530.0	46.0	502.0	
2:45	150.0	0.70	530.0	44.0	495.0	
3:00	153.0	0.70	530.0	42.0	515.0	
3:15	150.0	0.75	500.0	44.0	496.0	
3:30	151.0	0.70	505.0	44.0	492.0	
3:45	149.0	0.70	490.0	46.0	492.0	
4;00	155.0	0.70	525.0	46.0	497.0	
Ave.	150.0	.714	514.0	47.35	491.5	

LOG OF BOILER TEST NO.2.

Barometer	29.15
Date	January 26, 1911.

	Pressure		Temperature F°			
Time A.M.	Steam gage	Stack draft in. water	Stack temp.	Feed water	Steam at engine	Water level in gage glass
8:00	155:0	0.65	565.0	46.0	452.0	One inch above mark
8:15	151.0	0.75	555.0	46.0	452.0	
8:30	149.0	0.60	540.0	48.0	455.0	
8:45	149.0	0.50	560.0	51.0	490.0	
9:00	149.0	0.70	555.0	51.0	500.0	
9:15	150.0	0.70	555.0	58.0	502.0	
9:30	150.0	0.60	555.0	58.0	510.0	
9:45	152.0	0.70	580.0	50.0	508.0	
Ave.	150.4	.65	558.12	51.0	483.5	

LOG OF BOILER TEST NO.3.

Barometer 29.01

Date January 26, 1911

	Pressure		Temperature F°			
Time A.M.	Steam gage	Stack draft in. water	Stack temp.	Feed water	Steam at engine	Water level in gage glass
11:30	140.0	0.65	550.0	48.0	475.0	Water on mark
11:45	150.0	0.50	500.0	51.0	492.0	
12:00	150.0	0.40	550.0	54.0	495.0	
P.M.						
12:15	152.0	0.50	555.0	60.0	503.0	
12:30	150.0	0.50	555.0	58.0	505.0	
12:45	149.0	0.60	560.0	57.0	508.0	
1:00	148.0	0.60	530.0	58.0	513.0	
1:15	151.0	0.70	515.0	57.0	510.0	
1:30	147.0	0.70	530.0	57.0	502.0	
1:45	148.0	0.50	555.0	57.0	511.0	
2:00	148.0	0.60	525.0	57.0	502.0	
2:15	148.0	0.80	530.0	57.0	501.0	
2:30	146.0	0.60	530.0	56.0	504.0	
2:45	149.0	0.60	525.0	56.0	508.0	
3:00	150.0	0.80	505.0	56.0	506.0	
3:15	149.0	0.70	530.0	55.0	495.0	
3:30	151.0	0.60	520.0	55.0	500.0	
Ave.	148.7	0.61	533.0	54.8	501.0	

Note: Average temperatures for all tests:
Middle of boiler room 60° F.
By door in boiler room 56° F.
External air 41° F.

No boiler data available for test No.4, the reason of which is explained elsewhere.

LOG OF BOILER TEST NO.1.

Coal, Water, and Flue Gas Measurements.

Type of furnace	
Kind of fuel	Youghiogheny screenings
Kind of firing	Hand fired
Date of test	January 25, 1911.

	Flue Gas	COAL			WATER	
Time P.M.	% CO_2	Total Weight	On floor	Total used	Weight Tank No.1	Weight Tank No.2
12:00					2449	2455
12:15					2453	2473
12:30	7.0				2404	2425
12:45					2472	2420 2448
1:00	6.5	3825	250	3575	2450	2487
1:15					2423	2436
1:30					2464	2447
1:45	5.2				2508	2465
2:00		7395	900	6495	2427	2415
2:15	5.6				2441	2429
2:30					2440	2434
2:45					2454 2455	2464 2447
3:00		10710	---	10710	2450	2457
3:15	5.0				2420	2458
3:30					2514	2483
3:45					2451	2430
4:00		14025	---	14025		1441
Ave.	5.86			Total	41675	45514

Grand Total = 4)87189

Per hr.= 21797.25

LOG OF BOILER TEST NO.2.

Date of test January 26, 1911.

	Flue Gas	COAL			WATER	
Time A.M.	% CO2	Total Weight	On floor	Total used	Weight Tank No.1	Weight Tank No.2
8:00					2443	2620
8:15	8.5				2430	2459
8:30					2454	2739
8:45	7.0	5610	600	5010	2451	2428
					2451	
9:00					2426	2459
9:15	8:0				2426	2432
9:30					2434	2477
9:45					2700	2444
10:00		9435	900	8535	2427	2435
					2452	2436
						2472
Ave.	7.8			Total	27094	27401

Grand Total = 2)54495

Per hr. = 27247.5

Condensed Steam from Turbo for Make Up Water for Test No.1

Time: 3:44 to 4:44 P.M. January 26, 1911

	Weight Tank No.1	Weight Tank No.2
	2418	2437
	2469	2457
	2455	2442
	2470	2371
Total	9812	9707

Grand Total 19519

LOG OF BOILER TEST NO. 3

Coal, Water, and Flue Gas Measurements.

Date of test January 26, 1911.

	Flue Gas	COAL			WATER	
Time A.M.	% CO2	Total weight	On Floor	Total used	Weight Tank No.1	Weight Tank No.2
11:30					2467	2427
11:45	6.0				2434	2425
12:00					2680	2855
P.M.						
12:15					2431	2441
					2421	2423
					2430	
12:30	6.4	6120	700	5420	2446	2425
12:45					2443	2425
1:00	7.5				2435	2431
1:15					2459	2436
					2428	2451
1:30		11220	1200	10020	2414	2422
1:45	8.0				2411	2406
2:00					2417	2420
2:15	7.6				2422	2760
					2405	2418
2:30		14280		14280	2406	2460
2:45	7.6				2410	2434
3:00					2422	2400
3:15					2430	2491
					2413	2413
3:30		19380	470	18910	2400	2520
						2424
					Make up water	2400
						391
						499
				Total	53624	55195

Grand Total		4)108821
Per hr.	=	27205

LOG OF ENGINE DATA

Test No. 1 - January 25, 1911

High Pressure Cylinder		Low Pressure Cylinder	
Dia. of cylinder	22.0"	Dia. of cylinder	40.0"
Length of stroke	36.0"	Date of test -	Jan.25, 1911
Barometer	29.32"		

Speed			Pressures		
Time P.M.	Continuous Counter	R.P.M.	Steam Line Gauge	Re-ceiver	Condenser in.Mercury
12:00	54406	147.7	144.0	3.0	28.2
12:15	56621	147.7	142.0	4.0	28.2
12:30	58835	147.6	143.0	4.0	28.15
12:45	61050	147.6	142.0	4.0	28.05
1:00	63263	147.5	146.0	5.0	28.1
1:15	65476	147.5	146.0	5.0	28.1
1:30	67687	147.4	145.0	5.0	28.15
1:45	69903	147.7	147.0	5.0	26.78
2:00	72115	147.5	145.0	5.0	28.1
2:15	74328	147.5	150.0	4.0	28.15
2:30	76537	147.2	145.0	5.0	28.1
2:45	78751	147.6	138.0	4.0	28.15
3:00	80961	147.3	152.0	5.0	28.15
3:15	83161	146.6	152.0	4.0	28.05
3:30	85370	147.2	150.0	4.0	28.10
3:45	87605	149.0	148.0	4.0	28.1
4:00	89847	149.4	147.0	3.0	28.1
Ave.		147.5	146.0	4.29	28.05

Test No. 2 - January 26, 1911

Speed			Pressures		
Time A.M.	Continuous Counter	R.P.M.	Steam Line Gauge	Receiver	Condenser in.Mercury
8:00	08486		144.0	10.0	27.8
8:15	10695	147.2	145.0	10.0	27.8
8:30	12895	146.5	150.0	10.0	27.7
8:45	15087	146.2	147.0	10.0	27.75
9:00	17283	146.4	146.0	10.0	27.75
9:15	19478	146.3	152.0	11.0	27.78
9:30	21673	146.3	149.0	10.0	27.8
9:45	23869	146.4	150.0	10.0	27.8
10:00	25879	134.0	151.0	10.0	27.8
Ave.		146.4	148.0	10.1	27.76

Test No. 3 - January 26, 1911

	Speed		Pressures		
Time A.M.	Barometer reading	R.P.M.	Steam Line Gauge	Receiver	Condenser in.Mercury
11:30	29.02	146.4	138	11	27.85
11:45		146.4	145	11	27.85
12:00		146.6	147	11	27.45
P.M.					
12:15		146.3	145	11	27.8
12:30		146.5	147	11	27.85
12:45		146.4	150	11	27.8
1:00	29.02	146.2	145	11	27.85
1:15		146.2	150	11	27.9
1:39		146.0	145	12	27.85
1:45		146.3	147	10	27.9
2:00		146.3	150	10	27.9
2:15		146.3	145	10	27.9
2:30	29.01	146.5	143	10	27.85
2:45		146.5	149	10	27.9
3:00		146.5	150	10	27.85
3:15		146.3	149	10	27.87
3:30	29.01	146.5	153	10	28.0
Ave.	29.015	146.4	146.9	10.6	27.82

Test No. 4 - January 26, 1911

3:45		147.7	147	5	27.95
4:00		147.3	140	5	27.6
4:15		147.2	148	5	26.7
4:30		147.2	150	5	26.55
4:45		147.2	145	5	26.7
Ave.		147.3	147.5	5	27.1

TEMPERATURES

Test No. 1 - January 25, 1911.

Time P.M.	Steam at engine throttle	Steam entering turbine	Condensed steam leaving condenser	Cooling water entering	Condenser water leaving
12:00	467	192	53	34	42
12:15	470	192	50	34	41.6
12:30	485	192	50	34	42
12:45	484	193	51	34	42
1:00	494	194	51	34	43
1:15	495	192	51	34	42
1:30	485	193	48	34	43
1:45	498	194	46	34	43
2:00	500	193	46	34	42.5
2:15	504	192	46	34	43
2:30	502	192	46	34	42.5
2:45	495	194	44	34	43
3:00	515	191	42	34	42.5
3:15	496	192	44	34	41
3:30	492	192	44	34	41.5
3:45	492	192	46	34	41
4:00	497	190.5	46	34	41
Ave.	491.5	192.2	47.35	34	42

Test No. 2 - January 26, 1911.

Time A.M.	Steam at engine throttle	Steam entering turbine	Condensed steam leaving condenser	Cooling water entering	Condenser water leaving
8:00	452	208.5	46	34	43.5
8:15	452	204	46	34	43.5
8:30	455	208	48	34	43.5
8:45	490	208	51	34	43.5
9:00	500	206	51	34	43.5
9:15	502	206	58	34	46.3
9:30	510	206	58	34	43.5
9:45	508	207	50	34	44.0
10:00	508	206		34	44.0
Ave.	483.5	206.5	51	34	43.5

Test No. 3 - January 26, 1911.

Time A.M.	Steam at engine throttle	Steam entering turbine	Condensed steam leaving condenser	Cooling water entering	Condenser water leaving
11:30	475	210	48	34	44.5
11:45	492	208	51	34	44
12:00	495	208	54	34	44.5
P.M.					
12:15	503	208	60	34	44
12:30	505	206	58	34	43
12:45	508	208	57	34	44
1:00	513	207	58	34	43.5
1:15	510	206	57	34	43.5
1:30	502	207	57	34	43.5
1:45	511	206	57	34	43.5
2:00	502	207	57	34	43.5
2:15	501	208	57	34	43.3
2:30	504	206.5	56	34	43.5
2:45	508	207.5	56	34	43.5
3:00	506	206	56	34	43.5
3:15	495	207	55	34	43.5
3:30	500	209	55	34	43
Ave.	501	207.4	54.8	34	43.65

Test No. 4 - January 26, 1911

Time	Steam at engine throttle	Steam entering turbine	Condensed steam leaving condenser	Cooling water entering	Condenser water leaving
3:45	496	188		34	41
4:00	485	192		34	39.8
4:15	505	193		34	43
4:30	498	194		34	43
4:45	485	194		34	43
Ave.	497.2	192.2		34	41.96

INDICATOR CARDS

Test No. 1

Time P.M.	High Pressure M.E.P. Head	High Pressure M.E.P. Crank	Low Pressure M.E.P. Head	Low Pressure M.E.P. Crank
12:00	82.2	72.0	5.86	3.00
12:10	92.0	87.8	6.38	5.44
12:20	97.0	71.5	5.27	5.32
12:30	95.4	84.0	6.6	5.88
12:40	96.0	90.6	6.26	5.35
12:50	90.0	84.0	4.82	5.85
1:00	87.0	80.0	6.17	6.04
1:10	100.0	85.3	5.37	4.60
1:20	93.6	89.0	5.33	6.06
1:30	98.0	90.0	5.46	4.38
1:40	91.4	77.6	5.01	5.80
1:50	83.2	76.8	7.05	5.73
2:00	99.9	84.6	4.44	4.50
2:10	84.0	93.6	5.90	4.45
2:20	87.4	87.2	5.03	4.48
2:30	78.6	75.0	5.31	5.34
2:40	94.6	94.0	6.26	6.92
2:50	76.8	72.7	6.92	7.38
3:00	87.0	84.0	5.12	5.70
3:10	87.0	81.4	6.59	5.44
3:20	91.0	85.8	5.37	4.92
3:30	89.4	81.6	5.37	5.16
3:40	94.0	92.2	4.98	4.92
3:50	92.1	94.6	4.50	5.19
4:00	93.5	88.7	5.10	6.12
Ave.	90.2	84.4	5.63	5.35

Test No. 2

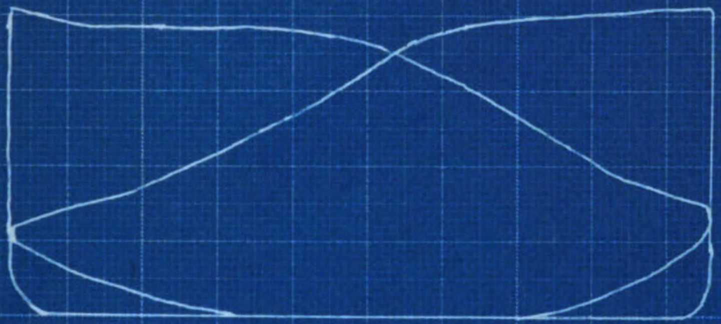
Time A.M.	High Pressure M.E.P. Head	 Crank	Low Pressure M.E.P. Head	 Crank
8:00	94.8	95.0	7.23	6.3
8:10	100.0	101.0	7.9	6.9
8:20	96.8	103.0	9.96	6.4
8:30	97.2	98.4	7.5	7.1
8:40	93.9	95.2	7.48	7.92
8:50	97.9	100.6	7.9	7.89
9:00	98.0	98.8	11.7	8.65
9:10	94.6	97.8	7.3	7.9
9:20	96.6	103.2	9.0	6.46
9:30	94.4	100.0	7.27	7.02
9:40	101.4	96.6	9.05	7.75
9:50	95.0	95.2	7.26	8.65
10:00	101.0	102.8	7.06	8.58
Ave.	96.7	98.8	8.21	7.84

Test No. 3

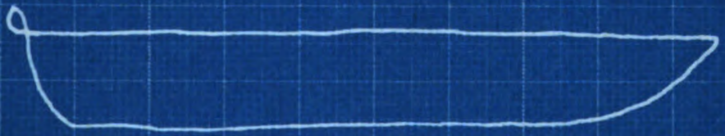
Time	High Pressure M.E.P.		Low Pressure M.E.P.	
P.M.	Head	Crank	Head	Crank
11:30	86.2	87.0	5.9	8.1
11:40	101.2	100.0	6.5	6.3
11:50	94.0	97.6	7.1	6.3
12:00	90.0	90.0	7.8	7.6
P.M.				
12:10	97.6	98.8	7.0	8.7
12:20	93.0	99.0	9.4	8.1
12:30	93.6	101.6	9.0	6.3
12:40	97.4	103.2	12.1	7.5
12:50	99.0	97.0	6.9	6.9
1:00	98.4	95.0	7.0	7.1
1:10	95.4	97.4	5.4	3.6
1:20	97.2	97.2	7.2	5.2
1:30	93.8	102.2	6.4	7.8
1:40	99.0	98.6	10.5	7.1
1:50	99.0	98.6	9.5	7.4
2:00	97.0	97.0	5.9	4.5
2:10	97.8	97.0	4.8	8.8
2:20	97.2	101.0	9.3	5.3
2:30	96.0	94.2	7.0	7.7
2:40	94.0	93.4	8.4	11.7
2:50	101.0	98.8	6.9	6.9
3:00	87.4	87.4	12.7	7.3
3:10	90.0	92.0	7.2	11.5
3:20	77.4	76.8	7.7	7.0
3:30	97.8	96.8	9.2	12.0
Ave.	94.4	95.3	7.84	7.46

Test No. 4

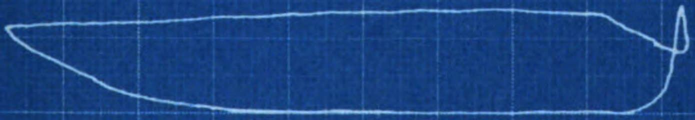
Time P.M.	High Pressure M.E.P. Head	High Pressure M.E.P. Crank	Low Pressure M.E.P. Head	Low Pressure M.E.P. Crank
3:50	86.6	82.6	4.77	4.49
4:00	87.8	89.2	4.27	3.9
4:10	93.0	96.0	5.6	4.7
4:20	92.8	96.6	5.63	4.9
4:30	90.8	94.2	4.41	6.0
4:40	91.6	86.4	4.8	4.7
4:50	91.4	93.1	3.9	4.7



HIGH PRESSURE

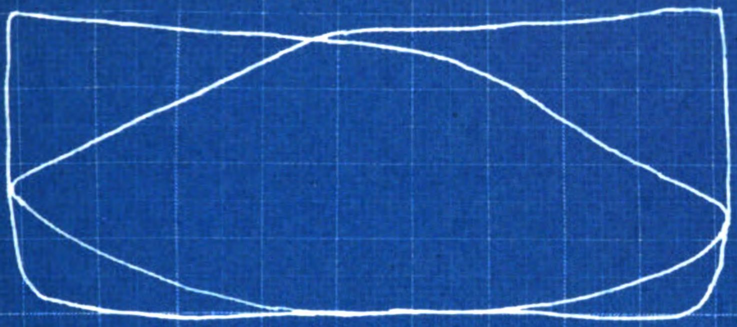


LOW PRESSURE H.E.

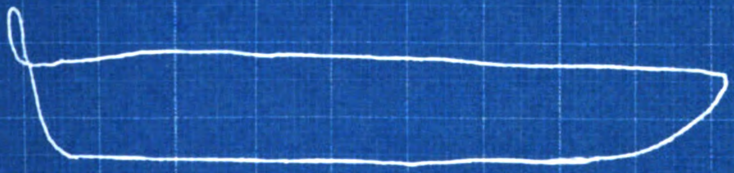


LOW PRESSURE C.E.

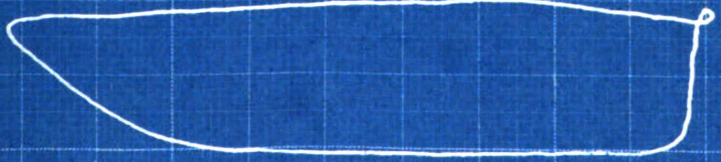
SAMPLE INDICATOR CARDS FROM TEST NO. 1



HIGH PRESSURE



LOW PRESSURE H.E.



LOW PRESSURE C.E.

SAMPLE INDICATOR CARDS FROM TEST NO. 3.

LOG OF CALORIMETER TEST.

Test No.1 - January 25, 1911.

	Run No.1	Run No.2	Run No.3	Run No.4
Turbine steam line temperature	192.6	193.0	192.2	191.6
Calorimeter temperature	207.1	208.5	205.0	201.0
Watts input in calorimeter	230.0	212.5	203.7	158.6
Duration in minutes	23	45	45	61
Weight of water condensed, lbs.	10.5	18.0	19.0	22.5
Average quality	97.2			

Test No.2 - January 26, 1911.

Turbine steam line temperature	206.9	206.2
Calorimeter temperature	225.3	218.8
Watts input in calorimeter	325.0	290.2
Duration in minutes	60	55
Weight of water condensed	29	27.5
Average quality	96.3	

Test No.3 - January 26, 1911.

Turbine steam line temperature	206.4	206.6	206.7	207.3
Calorimeter temperature	223.8	217.3	217.7	220.2
Watts input in calorimeter	293.5	249.0	214.5	247.5
Duration in minutes	41	60	51	42
Weight of water condensed	21	26.5	25.0	19.5
Average quality	96.8			

LOG OF ELECTRICAL DATA

500 k.w. 600/650 Volt D.C. Railway Generator

Test No. 1 - January 25, 1911

Time P.M.	Speed	Generator Output Amperes	Volts	Indicated k.w.	K.W.Hr. per hour
12:00	148	461	668	309	
12:30	148	462	670	310	
1:00	148	462	669	309	315
1:30	148	462	662	307	
2:00	148	462	669	309	310
2:30	148	454	672	306	
3:00	146	452	660	298	310
3:30	149.5	454	672	308	
4:00	150	444	660	293	320
Total					1255
Ave.	148.2	457	666.9	305.4	313.7

Test No. 2 - January 26, 1911

A.M.					
8:00	147.3	704	638	450	
8:30	147.5	692	628	431	
9:00	147.5	704	618	435	450
9:30	147.5	714	603	431	
10:00	147.3	695	608	423	448
Total					898
Ave.	147.2	701.8	619	434	449

Test No. 3 - January 26, 1911

		Generator Output			
Time A.M.	Speed	Amperes	Volts	Indicated k.w.	K.W.Hr. per hour
11:30	147	684	600	410	
12:00	147	699	623	436	
P.M.					
12:30	147	684	608	415	445
1:00	147	684	609	422	
1:30	147.3	654	638	417	450
2:00	147.2	704	638	449	
2:30	147.3	684	623	426	440
3:00	147.2	694	633	436	
3:30	147	724	632	458	445
Total					1780
Ave.	147.1	690.1	622.7	429.9	445

Test No. 4 - January 26, 1911

3:45	148.2	464	648	300	
4:15	148	454	658	299	
4:45	148.1	454	663	303	290
Ave.	148.1	457.3	656.3	301.7	290

RI^2 Losses in Railway Generator

Test No. 1 - January 25, 1911

Time P.M.	Armature	Field	Rheostat	Total
12:00	2761	4002	1364	8127
12:30	2768	4005	1348	8131
1:00	2768	4015	1350	8133
1:30	2768	4020	1345	8133
2:00	2768	4020	1333	7998
2:30	2682	4015	1301	7930
3:00	2655	4005	1270	7998
3:30	2682	4016	1300	7862
4:00	2561	4023	1278	8047
Ave.	2712.6	4013.4	1321	8039.9

Test No. 2 - January 26, 1911

A.M.				
8:00	6442	4206	1210	11858
8:30	6241	4218	1250	11709
9:00	6442	4201	1120	11763
9:30	6615	4195	1010	11820
10:00	6682	4205	961	11448
Ave.	6484.4	4205	1110.2	11719.6

Test No. 3 - January 26, 1911.

Time A.M.	Armature	Field	Rheostat	Total
11:30	6083	4200	968	11251
12:00	6355	4210	930	11495
P.M.				
12:30	6083	4210	900	11193
1:00	6033	4225	980	11238
1:30	5561	4206	1010	10777
2:00	6442	4251	1070	11763
2:30	6083	4244	1080	11407
3:00	6273	4231	1108	11612
3:30	6815	4206	1102	12123
Ave.	6191.8	4220.3	1016.4	11428.6

Test No. 4 - January 26, 1911

3:45	2894	4171	1260	8325
4:15	2682	4020	1248	7950
4:45	2682	4073	1251	8006
Ave.	2752.7	4088	1253	8093.7

LOG OF ELECTRIC DATA - A.C. GENERATOR

2300/4000 Volts, 60 Cycles, 3 Phase, 150 R.P.M., 500 K.V.A.

Test No. 1 - January 25, 1911.

			Amperes Phase			Volts Phase		
Time P.M.	Speed	Freq.	A	B	C	A	B	C
12:00	148	59.2	64	65	65	2260	2260	2260
12:30	148	59.2	65	65	65	2260	2260	2260
1:00	148	59.2	66	66	66	2280	2280	2280
1:30	148	59.2	66	66	66	2280	2280	2280
2:00	148	59.2	64	65	66	2280	2280	2280
2:30	148	59.2	65	67	65	2280	2280	2280
3:00	146	58.5	66	65	66	2280	2280	2280
3:30	149.5	59.8	66	66	66	2280	2280	2280
4:00	150	60	65	65	65	2300	2300	2300
Ave.	148	59.2	65.2	65.6	65.6	2277	2277	2277

Test No. 2 - January 26, 1911.

A.M.								
8:00	147.5	59	70	70	70	2400	2400	2400
8:30	147.5	59	69	70	70	2400	2400	2400
9:00	147.5	59	66	67	66	2400	2400	2400
9:30	147.3	58.9	69	69	69	2400	2400	2400
10:00	147.5	59	69	70	69	2400	2400	2400
Ave.	147.5	58.9	68.6	69.2	69.7	2400	2400	2400

Test No. 3 - January 26, 1911

Time A.M.	Speed	Freq.	Amperes Phase A	Amperes Phase B	Amperes Phase C	Volts Phase A	Volts Phase B	Volts Phase C
11:30	147.0	58.8	66	67	66	2400	2400	2400
12:00	147.0	58.8	69	70	70	2400	2400	2400
12:30	147.0	58.8	69	70	70	2400	2400	2400
1:00	142.3	58.9	68	69	69	2400	2400	2400
1:30	147.3	58.9	69	69	68	2400	2400	2400
2:00	147.3	58.9	67	68	67	2400	2400	2400
2:30	147.3	58.9	68	69	68	2400	2400	2400
3:00	147.3	58.9	66	67	65	2400	2400	2400
3:30	147.3	58.9	66	67	66	2400	2400	2400
Ave.	147.1	58.83	67.6	68.4	67.6	2400	2400	2400

Test No. 4 - January 26, 1911.

3:45	148.2	59.3	65	65	63	2260	2260	2260
4:15	148.0	59.2	67	69	69	2260	2260	2260
4:45	148.0	59.2	69	69	69	2260	2260	2260
Ave.	148.1	59.2	67	67.7	67	2260	2260	2260

Test No. 1 - January 25, 1911.

Time P.M.	K.V.A. Phase A	K.V.A. Phase B	K.V.A. Phase C	Indicated k.w. Phase A	Indicated k.w. Phase B	Indicated k.w. Phase C	Total
12:00	144.5	147.0	147.0	136	136	136	408
12:30	147.0	147.0	147.0	135	135	135	405
1:00	150.5	150.5	150.5	140	140	140	420
1:30	150.5	150.5	150.5	139	139	139	417
2:00	146.0	148.0	150.5	138	134	135	407
2:30	148.0	152.5	148.0	138	139	137	414
3:00	150.5	148.0	150.5	140.0	135	143	418
3:30	150.5	150.5	150.5	140	138	140	418
4:00	149.0	149.0	149.0	140	138	140	418
Ave.	148.4	149.3	149.4	138.3	137.2	138.3	414

Test No. 2 - January 26, 1911.

A.M.							
8:00	168.0	168.0	168.0	154	152	154	460
8:30	166.0	168.0	168.0	154	153	154	461
9:00	158.0	161.0	158.0	146	146	146	438
9:30	166.0	166.0	166.0	153	151	152	456
10:00	166.0	168.0	166.0	152	152	152	456
Ave.	165.0	166.0	165.5	152	151	151.6	454

Test No. 3 - January 26, 1911.

Time	K.V.A.			Indicated k.w.			
	Phase			Phase			
A.M.	A	B	C	A	B	C	Total
11:30	158.0	161.0	158.0	146	147	147	440
12:00	166.0	163.0	168.0	150	153	152	455
P.M.							
12:30	166.0	168.0	168.0	151	152	152	455
1:00	163.0	166.0	166.0	151	153	150	454
1:30	166.0	166.0	163.0	152	152	151	455
2:00	161.0	163.0	161.0	151	151	148	440
2:30	163.0	166.0	163.0	156	156	149	461
3:00	158.0	161.0	156.0	151	149	142	442
3:30	158.0	161.0	158.0	151	149	144	444
Ave.	162.0	164.0	162.0	151	151.3	148.4	448.5

Test No. 4 - January 26, 1911

3:45	147.0	147.0	142.5	135	138	136	409
4:15	151.5	156.0	156.0	149	148	149	446
4:45	156.0	156.0	156.0	150	148	149	447
Ave.	151.5	153.0	151.9	144.6	144.6	144.6	434

Test No. 1 - January 25, 1911.

Time	Power Factor			K.W.H. per Hour			
	Phase			Phase			
P.M.	A	B	C	A	B	C	Total
12:00	94.3	92.5	92.5				
12:30	92.0	92.0	92.0				
1:00	93.1	93.1	93.1	132	134	136	402
1:30	92.6	92.6	92.6				
2:00	94.8	90.8	89.9	135	135	134	404
2:30	93.0	91.2	92.3				
3:00	92.6	91.2	94.9	138	135	138	411
3:30	92.6	91.8	92.6				
4:00	94.0	92.8	94.0	135	132	134	401
Total				540	536	542	1618
Ave.	93.2	92.0	92.6	135	134.1	135.5	404.5

Test No. 2 - January 26, 1911.

A.M.							
8:00	91.5	90.6	91.5				
8:30	92.7	90.8	91.5				
9:00	92.7	90.6	92.7	148	150	148	446
9:30	92.0	91.0	91.9				
10:00	91.9	90.6	91.9	150	152	148	450
Total				298	302	296	896
Ave.	92.2	90.7	91.9	149	151	148	448

Test No. 3 - January 26, 1911.

	Power Factor			K.W.H. per Hour			
Time	Phase			Phase			
A.M.	A	B	C	A	B	C	Total
11:30	92.7	91.2	93.0				
12:00	90.6	93.8	90.3				
P.M.							
12:30	91.0	90.3	90.6	151	150	152	453
1:00	92.6	91.8	90.4				
1:30	91.9	91.8	92.8	151	148	148	447
2:00	92.6	92.5	92.0				
2:30	95.2	93.7	91.2	148	148	147	443
3:00	95.1	92.5	90.9				
3:30	95.1	92.5	91.0	148	149	148	445
Total				598	595	595	1788
Ave.	92.9	92.2	91.3	149.5	149	149	477

Test No. 4 - January 26, 1911.

3:45	91.8	93.7	95.4				
4:15	93.2	95.1	95.6				
4:45	96.1	95.1	95.6	145	145	143	433
Total				145	145	143	433
Ave.	93.7	94.6	95.5	145	145	143	433

Test No. 1 - January 25, 1911.

Time	Field		Exciter		Field	Rheo-
				K.W.H.	EI	stat
P.M.	Volt	Amp.	Volt	per hr.	loss	loss
12:00	101.0	79	115		7980	1120
12:30	101.5	80	117		8120	1230
1:00	101.5	80	119	9.36	8120	1230
1:30	102.0	80	127		8160	1540
2:00	103.0	80.5	122	9.75	8290	1560
2:30	103.0	80	122		8240	1560
3:00	104.0	80	123	9.8	8320	1530
3:30	104.0	81	123		8420	1550
4:00	104.0	80	123	9.8	8320	1650
Total				38.71		
Ave.	102.7	80.1	121.2	9.68	8220	1452

Test No. 2 - January 26, 1911.

A.M.						
8:00	102.0	88	122		8980	1380
8:30	103.0	88.5	120		9120	1230
9:00	103.0	88	119.5	10.5	9060	1180
9:30	104.0	88	120		9140	1160
10:00	105.0	88	121	10.60	9240	1150
Total				21.1		
Ave.	103.4	88	120.5	10.55	9108	1220

Test No. 3 - January 26, 1911.

Time A.M.	Field		Exciter		Field EI loss	Rheo-stat loss
	Volt	Amp.	Volt	K.W.H. per hr.		
11:30	103	88	125		9060	1940
12:00	104	88	125		9140	1860
P.M.						
12:30	105	88	126	11	9240	1810
1:00	105	88	127		9240	1850
1:30	105.5	88	119	10.7	9280	1160
2:00	105.5	88	119		9280	1160
2:30	106	88	119	10.5	9320	1120
3:00	106	88	119		9320	1120
3:30	106	88	119	10.5	9320	1120
Total				43.12		
Ave.	105.1	88	122	10.67	9250	1460

Test No. 4 - January 26, 1911.

3:45	103	80	120		8240	1410
4:15	103	80	121		8240	1410
4:45	103	80	121	9.65	8240	1410
Total				9.65		
Ave.	103	80	120.7	9.65	8240	1410

Test No. 1 - January 25, 1911.

Time P.M.	Losses			Total	Grand Total
	Arm. RI^2 Loss				
	Phase A	Phase B	Phase C		
12:00	754	774	774	2302	11402
12:30	774	774	774	2322	11672
1:00	798	798	798	2394	11744
1:30	798	798	798	2394	12194
2:00	754	774	798	2326	12176
2:30	774	824	774	2372	12172
3:00	798	774	798	2370	12220
3:30	798	798	798	2394	12364
4:00	774	774	774	2322	12292
Ave.	781	788	788	2355	12040

Test No. 2 - January 26, 1911.

A.M.					
8:00	897	897	897	2691	13051
8:30	870	897	897	2664	13014
9:00	798	824	798	2420	12660
9:30	870	870	870	2610	12910
10:00	870	897	870	2637	13027
Ave.	861	877	866.5	2604	12932

Test No. 3 - January 26, 1911.

	Losses				
	Arm. RI^2 Loss				
Time	Phase				Grand
A.M.	A	B	C	Total	Total
11:30	798	824	798	2420	13420
12:00	870	897	897	2664	13664
P.M.					
12:30	870	897	897	2664	13710
1:00	846	870	870	2586	13676
1:30	870	870	846	2586	13062
2:00	824	846	824	2494	12934
2:30	846	870	846	2562	13002
3:00	798	824	774	2396	12836
3:30	798	824	798	2420	12860
Ave.	835	858	839	2532	13236

Test No. 4 - January 26, 1911.

3:45	774	774	725	2273	11923
4:15	824	870	870	2564	12214
4:45	870	870	870	2610	12260
Ave.	823	838	821.7	2482	12132

LOG OF ELECTRIC DATA
LOW PRESSURE TURBO-ALTERNATOR

2300/4000 Volts, 60 cycles, 3 Phase,
3600 R.P.M., 1250 k.w.

Test No. 1 - January 25, 1911.

Time			Amperes			Volts		
			Phase			Phase		
P.M.	Speed	Freq.	A	B	C	A	B	C
12:00	3555	59.2	70	70	70	2240	2240	2240
12:30	3555	59.2	71	71	71	2270	2270	2280
1:00	3555	59.2	73	73	73	2280	2280	2290
1:30	3555	59.2	73	73	73	2270	2270	2280
2:00	3555	59.2	70	71	72	2260	2260	2260
2:30	3555	59.2	73	71	72	2280	2280	2270
3:00	3510	58.5	70	70	70	2280	2280	2280
3:30	3590	59.8	72	71	73	2280	2280	2280
4:00	3600	60.0	73	69	73	2280	2280	2286
Ave.	3559	59.3	71.6	71	71.9	2271	2271	2274

Test No. 2 - January 26, 1911

A.M.								
8:00	3540	59	100	98	100	2400	2400	2400
8:30	3540	59	99	98	100	2420	2420	2420
9:00	3540	59	100	99	99	2400	2400	2400
9:30	3538	58.9	95	97	97	2400	2400	2400
10:00	3540	59	95	94	95	2400	2400	2400
Ave.	3538	58.95	98	97.2	98.1	2404	2404	2404

Test No. 3 - January 26, 1911.

			Amperes			Volts		
			Phase			Phase		
Time A.M.	Speed	Freq.	A	B	C	A	B	C
11:30	3555	58.8	106	107	107	2400	2400	2400
12:00	3555	58.8	100	100	100	2400	2400	2400
P.M.								
12:30	3555	58.8	96	97	98	2400	2400	2400
1:00	3555	58.8	98	97	98	2400	2400	2400
1:30	3555	58.8	96	96	95	2400	2400	2400
2:00	3555	58.8	97	98	99	2400	2400	2400
2:30	3555	58.8	96	96	98	2400	2400	2400
3:00	3555	58.8	97	96	98	2400	2400	2400
3:30	3555	58.8	103	102	102	2400	2400	2400
Ave..	3555	58.8	98.8	98.8	99.4	2400	2400	2400

Test No. 4 - January 26, 1911.

3:45	3560	59.3	63	67	67	2260	2260	2260
4:15	3555	59.2	60	67	66	2260	2260	2260
4:45	3555	59.2	65	68	67	2260	2260	2260
Ave.	3557	59.2	62.6	67.3	66.7	2260	2260	2260

Test No. 1 - January 25, 1911.

Time	K.V.A. Phase			Indicated k.w. Phase			
P.M.	A	B	C	A	B	C	Total
12:00	157.7	157.0	157.0	150	150	155	455
12:30	161.5	161.5	162.0	160	160	160	486
1:00	166.5	166.5	167.0	166	166	166	498
1:30	166.0	166.0	166.5	164	164	164	492
2:00	158.0	160.5	163.0	152	153	154	459
2:30	166.5	162.0	163.5	155	150	155	460
3:00	159.5	159.5	159.5	155	155	155	465
3:30	164.0	162.0	166.6	152	150	155	457
4:00	166.6	158.0	166.6	153	150	154	457
Ave.	162.9	161.4	163.5	156.4	155.2	157.5	470

Test No. 2 - January 26, 1911.

A.M.							
8:00	240	236	240	235	230	235	700
8:30	240	237	242	235	230	235	700
9:00	240	238	238	235	230	235	700
9:30	228	233	233	225	220	225	670
10:00	228	226	228	220	220	225	665
Ave.	235	234	236	230	226	230.9	687

Test No. 3- January 26, 1911.

Time	K.V.A.			Indicated k.w.			
	Phase			Phase			
A.M.	A	B	C	A	B	C	Total
11:30	257	258	258	247	248	247	742
12:00	240	240	240	238	236	237	711
P.M.							
12:30	231	233	235	228	230	230	688
1:00	235	233	235	228	230	230	688
1:30	231	231	228	222	225	225	672
2:00	233	235	238	225	230	230	685
2:30	231	231	235	224	225	225	674
3:00	233	231	235	230	230	235	700
3:30	247	245	245	238	240	240	718
Ave.	237.5	237.4	238.6	231	232.7	233.2	698

Test No. 4 - January 26, 1911.

3:45	142.5	151.5	151.5	138	145	150	433
4:15	136	151.5	149	135	150	145	430
4:45	147	154	151.5	134	150	145	429
Ave.	141.8	152.3	150.6	136	148	146	431

Test No. 1 - January 25, 1911.

Time	Power Factor Phase			K.W.H. per Hour Phase			
P.M.	A	B	C	A	B	C	Total
12:00	95.5	95.5	98.4				
12:30	99.1	99.1	97.5				
1:00	99.6	99.1	99.6	164	162	164	490
1:30	98.8	98.8	98.2				
2:00	96.2	95.2	94.5	158	158	157	473
2:30	93.0	92.5	94.8				
3:00	97.2	97.2	97.2	158	159	160	477
3:30	92.7	92.8	93.2				
4:00	91.7	95.0	92.3	156	157	157	470
Total				636	636	638	1910
Ave.	96.0	96.2	96.1	159	159	159.5	477.5

Test No. 2 - January 26, 1911.

A.M.							
8:00	97.8	97.2	97.8				
8:30	97.8	97.0	97.1				
9:00	97.8	96.7	98.5	230	228	231	689
9:30	98.7	94.2	96.1				
10:00	96.8	97.2	98.6	229	224	230	682
Total				458	452	461	1371
Ave.	97.8	96.5	97.6	229	226	230.5	685.5

Test No. 3 - January 26, 1911.

Time	Power Factor			K.W.H. per Hour			
	Phase			Phase			
A.M.	A	B	C	A	B	C	Total
11:30	96	96	95.3				
12:00	98.9	98.5	98.3				
P.M.							
12:30	98.2	98.7	98.0	242	242	240	724
1:00	98.1	98.4	97.3				
1:30	96	97.1	98.8	240	238	238	716
2:00	96.2	97.5	96.3				
2:30	96.7	97	95.7	240	240	238	718
3:00	98.6	97.8	100				
3:30	96.2	97.6	97.6	242	240	242	724
Total				964	960	958	2882
Ave.	97.2	97.6	97.5	241	240	239	720.5

Test No. 4 - January 26, 1911.

Time	Power Factor A	Power Factor B	Power Factor C	K.W.H. A	K.W.H. B	K.W.H. C	Total
3:45	98.9	99.4	99.6				
4:15	99.2	98.6	97.2				
4:45	91.2	97.3	96.0	140	143	143	426
Total				140	143	143	426
Ave.	96.8	98.4	97.6	140	143	143	426

Test No. 1 - January 25, 1911.

Time P.M.	Field		Exciter		Field EI loss	Rheostat loss
	Volt	Amp.	Volt	K.W.H. per hr.		
12:00	44	52	115		2288	3697
12:30	44.5	52	117		2314	3768
1:00	45	53	119	6.15	2385	3927
1:30	45.5	52	122		2366	3979
2:00	46.5	52	122	6.35	2418	3927
2:30	46.5	52	122		2418	3984
3:00	47	52	123	6.4	2444	3956
3:30	47	52	123		2444	3956
4:00	47	52	123	6.4	2444	3956
Total				25.3		
Ave.	45.9	52.1	120.6	6.35	2390	3900

Test No. 2 - January 26, 1911.

A.M.						
8:00	49	58	122		2842	4243
8:30	50	58	120		2900	4060
9:00	51	58	120	7.0	2958	4002
9:30	51	58	120		2958	4002
10:00	52	58	121	7.0	3016	4004
Total				14.0		
Ave.	50.6	58	120.6	7.0	2935	4062

Test No. 3 - January 26, 1911.

Time A.M.	Field		Exciter		Field EI loss	Rheo-stat loss
	Volt	Amp.	Volt	K.W.H. Per hr.		
11:30	51	58	125		2958	4292
12:00	52	58	125		3016	4234
P.M.						
12:30	53	58	126	7.3	3074	4226
1:00	53	58	127		3074	4291
1:30	53.5	58	119	7.0	3103	3799
2:00	54	58	119		3132	3730
2:30	54	58	119	6.9	3132	3730
3:00	54	58	119		3132	3730
3:30	54	58	119	6.9	3132	3730
Total				28.1		
Ave.	53.2	58	122	6.52	3083	3968

Test No. 4 - January 26, 1911

3:45	47	52	120		2444	3806
4:15	47	52	121		2444	3856
4:45	46	52	121	6.3	2392	3908
Total				6.3		
Ave.	46.6	52	120.6	6.3	2426	3857

Test No. 1 - January 25, 1911.

	Losses				
	Arm. RI^2 Loss				
	Phase				
Time P.M.	A	B	C	Total	Grand Total
12:00	127	127	127	381	6366
12:30	131	131	131	393	6475
1:00	138	138	138	414	6726
1:30	138	138	138	414	6759
2:00	127	131	134	392	6737
2:30	138	131	134	403	6805
3:00	127	127	127	381	6781
3:30	134	131	138	403	6803
4:00	138	124	138	400	6801
Ave.	133	131	134	398	6700

Test No. 2 - January 26, 1911.

A.M.					
8:00	260	249	260	769	7854
8:30	254	249	260	763	7732
9:00	260	254	254	768	7728
9:30	238	244	244	726	7686
10:00	238	231	238	707	7727
Ave.	250	245	251	746	7740

Test No. 3 - January 26, 1911.

Time	Losses				
	Arm. RI^2 Loss				
	Phase				Grand
A.M.	A	B	C	Total	Total
11:30	293	296	296	885	8135
12:00	260	260	260	780	8030
P.M.					
12:30	239	244	249	732	8032
1:00	249	244	249	742	8107
1:30	239	239	238	716	7618
2:00	244	249	254	747	7649
2:30	239	239	249	727	7629
3:00	244	239	249	732	7634
3:30	277	271	271	819	7721
Ave.	254	253.6	257	764.4	7840

Test No. 4 - January 26, 1911.

3:45	98	114	114	326	6576
4:15	93	114	113	320	6620
4:45	108	119	114	343	6642
Ave.	100	115.6	113.6	329.6	6612

Approved:

A.G.Christie
Ass't. Prof. of Steam Engineerin

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